Performance modeling of finite-source cognitive radio networks with reverse balking and reneging using simulation

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***Abstract*—Understanding the impatient behaviour of users and customers has a critical importance for every organization to remain at the forefront in today's competitive business world.**

Customers' most prevalent impatient behaviours are balking and reneging. Customers are discouraged about receiving service when they notice large queues ahead (balking); they may even exit the system after joining if their wait time exceeds expectations (reneging). Nevertheless, in the investment-related industry, the opposite of balking is true, the desire to join a business is great if the number of customers is high, as this can be a very attractive factor for new investors. If the number of existing clients is large, the possibility of connecting to such a business is significant. Thus, the more crowded the system, the more joiners and vice versa (reverse balking).

In this article, we study the concepts of reneging and reverse balking in the context of a Cognitive Radio Network. The more crowded our network is, the more likely new calls join, and vice versa. These calls, may also get irritated and abandon the whole system as a result of a lengthy delay. The system's key performance measures are visually illustrated and acquired using simulation.

***Index Terms*—finite source queuing systems, simulation, reneging, reverse balking, cognitive radio networks, performance measures.**

I. INTRODUCTION

”CR” Cognitive Radio is a smart technology that allows increasing the efficiency of a substantially underused spectrum, by exploiting free sections and allocating them to other users to enhance systems performance.

A Cognitive Radio Network (CRN) may be built using CRs; this kind of network extends radio link capabilities to network layer operations. The network can sense its surroundings, learn from history, and decide based on ideal spectrum settings by adjusting the transmission parameters, enabling more communications to establish, thanks to the collaboration of CRs.

The system's essential aim is to maximize free spaces within the spectrums. More information may be found [1], [2], [3], [4], [5] and [6].

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That is to say, CRN enables more effective use of the available spectrum by distinguishing between primary and secondary customers in wireless networks.

Based on an exponential distribution manner, primary users calls (PU) of our system are originated from a defined finite number of sources. All the calls are directed to a FIFO (first-in, first-out) queue. Secondary users (SU) are created using an exponential distribution and sent to the secondary channel service (SCS). Service times for PU and SU are similarly exponentially distributed.

If the principal channel service (PCS) is available, the service may begin right away for new generated licensed calls; if it is currently in use by another primary call, this call will be sent to the FIFO queue. If the PCS is held by a secondary user, the service will be halted and forwarded to the SCS. Depending on its present state, the aborted call will be reinstated from the start of its service or put in the retrial queue (orbit).

In a slightly similar manner, SCS is handling the queries of SUs. If this channel is idle upon the arrival of a new SU call, service is straightway started; otherwise, the latter user may seek to initiate service in the PCS, opportunistically, if it is free, the call will be treated in the primary band. Supposing that the PCS is not available either, the low-priority call will be redirected to the orbit, from which the same call will retry to get service after an exponentially distributed time.

Several studies dealt with CRN upon many scenarios, as an example, in [3], both servers of the CRN were subject to some random breakdowns and repairs, the servers unreliability was investigated. The authors of [6], modified the model to include abandonment, some inetresting results were shown, the performance of the system was enhanced, as SUs were forced to leave the system if their cumulative waiting time surpassed the maximum waiting time. On the other hand, reneging and reverse were investigated in queuing systems, including [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [21], [22], [23], [24], [25], [26], [27], [28] and [29]. Despite a thorough review of several relevant studies, we were unable to find any study that addressed this model while taking reverse balking and reneging into consideration, which is the uniqueness of our work.

Customers' impatient behaviour is typically analyzed using two queuing terms: balking and reneging. When a client balks, he decides not to join the queue since there is a long line ahead. Reneging happens when a customer is waiting in the queue, his waiting time starts to get long, so he decides to leave the system. The number of users in the queueing system determines impatient behaviour in each of these cases. There would be less balking and reneging if there were fewer users in the system.

When it comes to investment firms, however, consumers prefer to join those companies that already have a high number of customers. Clients are typically hesitant to join financial institutions (banks, mutual funds, insurance companies, and so on) that have a small number of customers or are new to the market. As a result, customers' decisions to join or not join a system/business cannot always be accurately predicted by typical balking. In reality, the decision-making position has flipped, and the probability of a new user joining the system raises if the number of customers in the system increases. This behaviour is referred to as "reverse balking."

II. SYSTEM MODEL

Our system (finite source queuing system that models a CRN) illustrated in Figure 1. consists of two interlinked subsystems. The first section generates primary calls from a finite number of sources N_1 and routed to the first primary server seeking service. The inter-request and service times are exponentially distributed with parameter $1/\lambda_1$ and μ_1, respectively. The call is handled immediately in the PCS if the unit is available; else, the call will be placed in the preemptive priority queue.

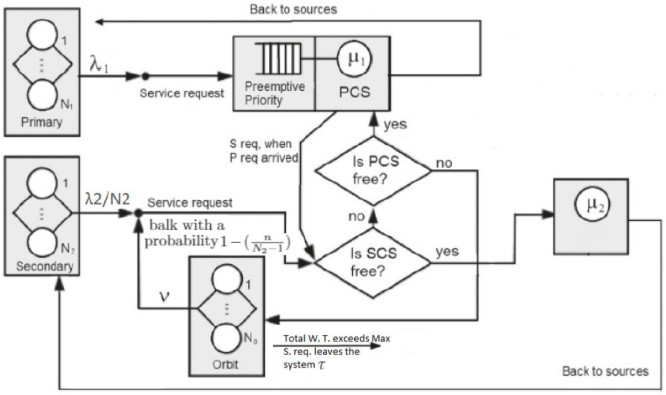

Figure 1. CRN with reverse balking and reneging

Table I
THE SIMULATION'S PARAMETERS

Parameters	Notation
Licensed sources	N_1
Unlicensed Sources	N_2
Licensed arrival rate	λ_1
Unlicensed arrival rate	λ_2
Licensed service rate	μ_1
Unlicensed service rate	μ_2
Retrial rate	ν
Reneging rate	τ

The secondary subsystem number of sources is finite and denoted by N_2, generating exponentially unlicensed calls with the parameter λ_2/N_2. However, with a rate of μ_2, the SU service time is generally distributed using hyper-exponential, hypo-exponential and gamma. It should be noted that the same mean is used for these distributions, unlike the variances which are different. As mentioned, in the introduction section, SUs placed in the orbit keep trying to get service after a retrial random time which is exponentially distributed with parameter ν.

It is tricky and time-consuming to get the first customer to enter the system (customers are discouraged due to the reverse balking effect). The first secondary customer will enter the system with a probability of $1-p$, while p is the probability of balking (refusing to join the system).

Once we have at least one call in the system, new queries will balk with a probability of $1-q$ and join with a probability of q=$(\frac{n}{N_2-1})$, where n is the number of SU in the system at time t. This is known as "reverse balking."

Reneging of unlicensed users will be happening if the sum of the waiting times exceeds an exponentially distributed random variable with parameter τ.

Table II contains all the mentioned input parameters.

To build a stochastic process that characterizes the system's behaviour, we utilize the notations listed below:

- $k_1(t)$: primary sources within the system at time t;
- $k_2(t)$: secondary sources within the system at time t;
- $q(t)$: licensed calls in the FIFO queue at time t;
- $o(t)$: calls in the orbit at time t;
- $y(t)=0$, if the PCS is available, $y(t)=1$, if it is occupied by a primary customer, and $y(t)=2$, if it is busy with an unlicensed request at time t;
- $c(t)=0$, if SCS is available and $c(t)=1$, if is occupied at time t.

Consequently, we can get the following:

$$k_1(t)=\begin{cases} N_1-q(t), & y(t) = 0,2 \\ N_1-q(t)-1 & y(t) = 1 \end{cases}$$

$$k_2(t)=\begin{cases} N_2-o(t)-c(t), & y(t) = 0,1 \\ N_2-o(t)-c(t)-1 & y(t) = 2 \end{cases}$$

N_1	N_2	λ_1	λ_2/N_2	μ_1	μ_2	ν	p	τ
35	70	0.04	x-axis	2	2	25	0.6	0.3

Table II
SIMULATION INPUT PARAMETERS

III. SIMULATION RESULTS

This section investigates the impact of service time distributions and cognitive technologies on the system's primary performance measures. To get all the essential performance measures, we used a simulation approach. The stochastic simulation program was written on C programming language using SimPack [18]. We were able to deal with some generally distributed random variables reflected several times in the model's development, thanks to simulation. Getting an analytical solution to the performance measures when all the random variables are exponentially distributed is very challenging, if not impossible. For estimations, we employed the batch means method; see [19] and [20].

All of the numerical results were obtained after validating the simulation outputs. Table II shows the numerical values for the simulation main class input parameters, whereas Table III shows the numerical values for the simulation program's statistics class.

Table III
GENERAL DISTRIBUTIONS PARAMETERS

Distribution	Gamma, c_x^2 <1	Hyper	Hypo	Gamma, c_x^2 >1
Parameters	α = 1,78 β = 1,76	p = 0,33 λ_1 = 0,66 λ_2 = 1,33	λ_1 = 1,48 λ_2 = 3,06	α = 0,39 β = 0,39
Mean	1	1	1	1
Variance	0.56	2.56	0.56	2.56
c_x^2	0.56	2.56	0.56	2.56

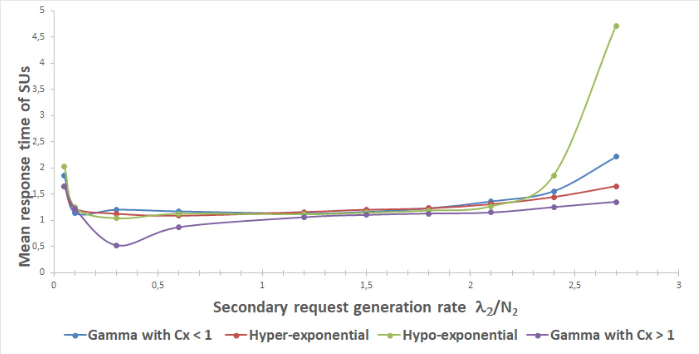

Figure 2. The influence of secondary service time distribution on SU mean residency time versus secondary request time generation

Figure 2. Illustrates secondary service time distribution's impact on the average response time of SU versus secondary inter-request time. When service times are gamma-distributed with $c_x^2 > 1$, the sensitivity of the distribution may be clearly seen, especially at the beginning of the simulation.

Furthermore, an interesting behaviour was noticed on this graph, the increase of the second generation rate did not result any significant effect on the mean residence time of SU, until the value of 2.7, where the mean has increased significantly.

The reverse balking effect may be concluded from this, as newly generated requests were more encouraged to join the system as time passed.

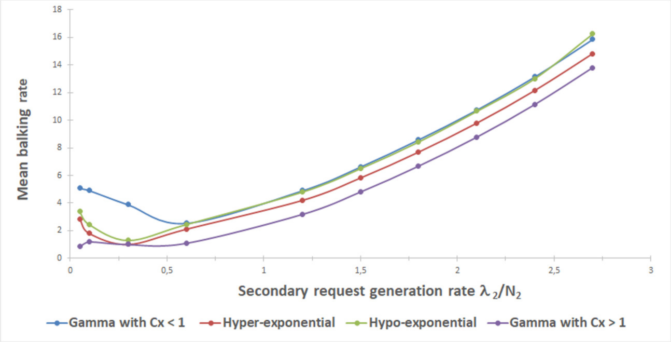

Figure 3. The influence of low-priority service time distribution on the mean SU balking rate against secondary request time generation

The influence of the secondary subsystem's service time distribution on the mean balking rate versus λ_2 is seen in Figure 3. In the Gamma distribution, increasing the secondary arrival rate causes incoming secondary users to become increasingly discouraged. When $c_x^2 > 1$, the service time is high, according to the Gamma distribution function, causing the system to overload.

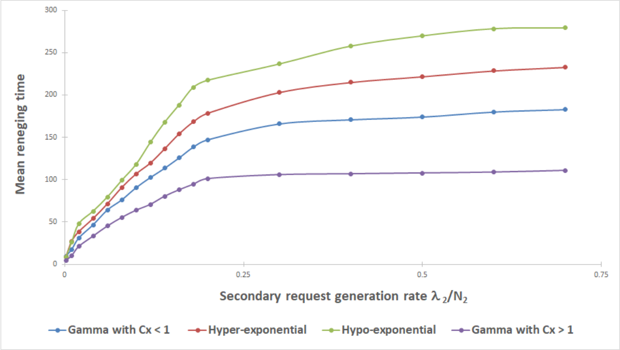

Figure 4. The effect of high-priority and low-priority service time distribution on unlicensed users' mean reneging time versus secondary request time generation

The impact of primary and secondary service time distributions on the mean reneging time of unlicensed users vs secondary request time generation is depicted in Figure 4. We

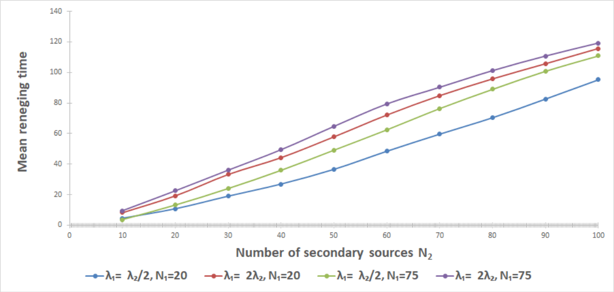

Figure 5. The effect of primary subsystem parameters on the average reneging time of SUs versus N_2

can see a significant sensitivity between the used distributions. Once more, the noteworthy thing about this graph is that it has a noticeable sensitivity when using c_x^2 greater or less than one. Although the same mean was utilized, the value of c_x^2 causes an important effect. With that being said, the influence of the squared coefficient of variation is now confirmed.

Other effects are shown in Figure 5., where modifying the primary number of sources has an impact on the outcomes, especially when $N_1 = 75$. More secondary users leave the system, leading to a longer mean reneging time. The system's reaction to cognitive technology is as follows.

IV. CONCLUSION

This study presents a finite-source retrial queueing system with two non-independent components. The goal of our system was to create a cognitive radio network with primary and secondary service units, as implementing reverse balking and reneging. The simulation was used to investigate the impact of service time distributions and cognitive technologies on the system's major performance measures. Several sample cases were obtained using simulation to demonstrate these impacts.

While c_x^2 is greater than one, an important distribution sensitivity was noticed. Reverse balking has shown a slow utilization of the system at the start of the simulation; but, as time passes, the system gets more congested; in certain circumstances, this occurs suddenly.

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